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HOW DOES THE ELASTIC SCATTERING OF $^{12}C + ^{20}Ne$ COMPARE WITH THAT OF $^{16}O + ^{16}O$?

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Résumé. — Les fonctions d'excitation de cinq voies de sortie du système $^{12}C + ^{20}Ne$ entre 22 et 28 MeV (C.M.) présentent une structure importante à 90° et 130° (C.M.). Cette structure, analogue à celle qu'on observe pour $^{16}O + ^{16}O$ est analysée en termes d'accord des moments angulaires. On présente une distribution angulaire à 24,7 MeV (C.M.). Il est montré que l'absorption due aux voies directes est intermédiaire entre celle de $^{16}O + ^{16}O$ et $^{18}O + ^{18}O$.

Abstract. — Excitation functions for 5 exit channels of the $^{12}C + ^{20}Ne$ system are given in the range 22-28 MeV centre of mass incident energy. An important structure is observed in the elastic scattering excitation functions taken at 90° and 130° (C.M.). This structure, which reminds one of the $^{16}O + ^{16}O$ case, is studied in terms of angular momentum matching. An angular distribution taken at 24.7 MeV (C.M.) is also presented. The direct channel absorption is shown to be intermediate between the $^{16}O + ^{16}O$ and $^{18}O + ^{18}O$ cases.

Since the observation [1] of a strong gross structure in the $^{16}O + ^{16}O$ elastic scattering functions, many other systems of identical or non identical light nuclei have been studied [2]. It was soon recognized that the observed structure is not a specific feature of identical particles (i.e. not due to the lack of odd-partial waves in the scattering amplitude) as the $^{18}O + ^{18}O$ system shows a strongly damped structure and a small average cross-section. Upon considerations on angular momentum matching between the entrance channel and the reaction channels, it was suggested [3] that the pronounced structure and the large cross-sections observed in the $^{16}O + ^{16}O$ elastic scattering were related to the inability for this system to carry away through the *direct* reaction channels the large angular momentum brought in by the grazing waves of the entrance channel. In terms of optical-model parameters, this implies that the magnitude of the average cross-section is roughly determined by the strength of the imaginary potential, whereas the peak-to-valley ratio critically depends on its transparency for the grazing partial waves. Such an interpretation seems to be strongly supported by the impressive improvements of the fits to the experimental data, obtained when an l-dependent imaginary potential is used [4]. Potentials of this type are able to explain the appearance of shape resonances. The existence, in the $^{16}O(^{16}O, ^{12}C)\,^{20}Ne$ reaction [5, 6] of a similar structure has been interpreted as evidence for such a mechanism. This coupling may, however, also be explained by considerations based on the 1-space localisation of the 4-particle transfer [6], [11]. From this viewpoint, the comparison of the $^{12}C + ^{20}Ne$ system with the $^{16}O + ^{16}O$ system is of interest. In terms of angular momentum matching, it has been shown by Vandenbosch, Webb and Zisman [7] that some differences should exist between them and result in a more damped structure and smaller cross-sections in the $^{12}C + ^{20}Ne$ system. This seems to be supported by their data, which was however limited for experimental reasons to smaller (80°) centre of mass (C.M.) angles.

In this letter, we present excitation functions of the $^{12}C + ^{20}Ne$ system for the elastic channel and the 4 reaction channels which are best matched with the entrance channel. These measurements, performed at 70°, 90° and 130° (C.M.) show for the backward angles some interesting differences with the conclusions of reference [7]. An elastic scattering angular distribution at 24.7 MeV (C.M.) incident energy is also given.

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Experimentally, using a ^{20}Ne beam allows standard detection and identification of the reaction products, even for backward angles and negative Q-value channels. The ^{20}Ne ions were accelerated by the I.S.N. Grenoble Cyclotron. The beam energy, as measured by magnetic analysis, is considered to be known within an absolute accuracy of 500 keV (lab.), and the energy dispersion of the beam to be approximately 400 keV (lab.), that is 150 keV (C.M.). Several values of beam energy for the excitation functions were obtained by slowing down the incident ions through carbon foils. It was checked that the beam quality suffered no significant deterioration.

The experimental set-up comprised two different systems of detection. For centre of mass angles close to 90°, particles were identified by the associated-particle method in two 200 mm^2 solid-state surface-barrier detectors. One was kept fixed at 45° (lab.) while the position of the other was adjusted to obtain the maximum counting rate. For the excitation function measurements, the solid angle was as large as 2.4 msr. The presented excitation functions are averaged over a $\pm$ 3° (C.M.) horizontal angle. For the elastic scattering angular distribution, this value was brought down to $\pm$ 1° (C.M.). With this system, the energy resolution was limited mainly by the target thickness (100 $\mu g/cm^2$) and by the beam energy dispersion. Special care was taken to make sure of the maximum efficiency of the system, but no correction has been applied (e.g. for in flight gamma decay of an excited nucleus or multiple scattering). The other detecting system was a standard $\Delta E - E$ telescope (10 μm) for detection and identification of reaction products emitted in a 0.2 msr. solid angle at a laboratory angle $\leqslant$ 25° (lab.), (i.e. $\leqslant$ 70° (C.M.) if ^{20}Ne are detected or $\geqslant$ 130° (C.M.) if recoil ^{12}C are detected). Energy resolution in that case is severely limited by kinematical broadening and was about 1 MeV for the ^{20}Ne ions detected at 25° (lab.). Relative cross-sections were determined from $^{20}Ne + {}^{197}Au$ Rutherford scattering. Absolute cross-sections are given within an accuracy of 25 %.

The elastic scattering excitation functions appear in figure 1. At 70° (C.M.), it is strongly decreasing, without any strong structure and in excellent agreement with the results of Vandenbosch, Webb and Zisman [7]. Excitation functions at 70° for the $^{12}C + {}^{20}Ne$ and the $^{16}O + {}^{16}O$ systems were compared in reference [7]. It was concluded that the different behaviour of the excitation functions was due to a larger absorption for high l-values in the $^{12}C + {}^{20}Ne$ case. In contrast with what is observed at 70°, both the 90° (C.M.) and the 130° (C.M.) elastic scattering excitation functions clearly show a structure. It is well-known that, at 90° (C.M.) the absence of odd-partial waves in the scattering amplitude can give more pronounced structure to the cross-section, but this argument no longer holds at 130° where a similar structure is observed. The 90° excitation function is quite comparable to the $^{16}O + {}^{16}O$ one at the same angle. The main differences are in the peak-to-valley ratio, which is slightly smaller (though the limited energy and angular resolution of this experiment can account for some reduction of this value), and in the absolute values of the cross-sections, one order of magnitude smaller for $^{12}C + {}^{20}Ne$, even if the identity of particles in the $^{16}O + {}^{16}O$ system is taken into account.

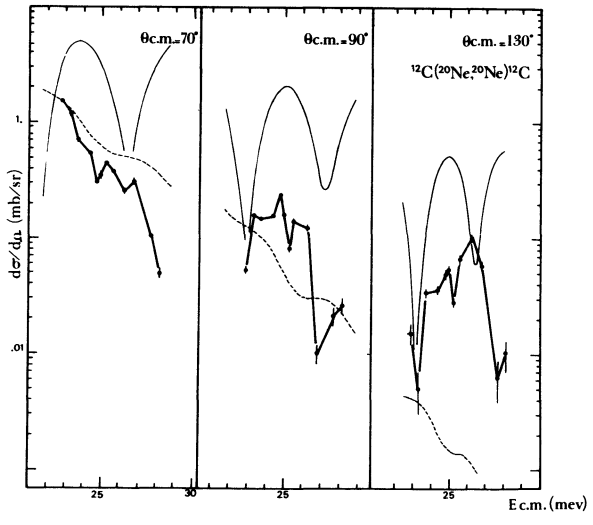

FIG. 1. — Excitation functions of the $^{12}C + {}^{20}Ne$ elastic scattering thick full curve guides the eye between experimental points thin full line = optical model predictions with the potential of reference [8] dashed line = optical model predictions with the potential of reference [7] (see text).

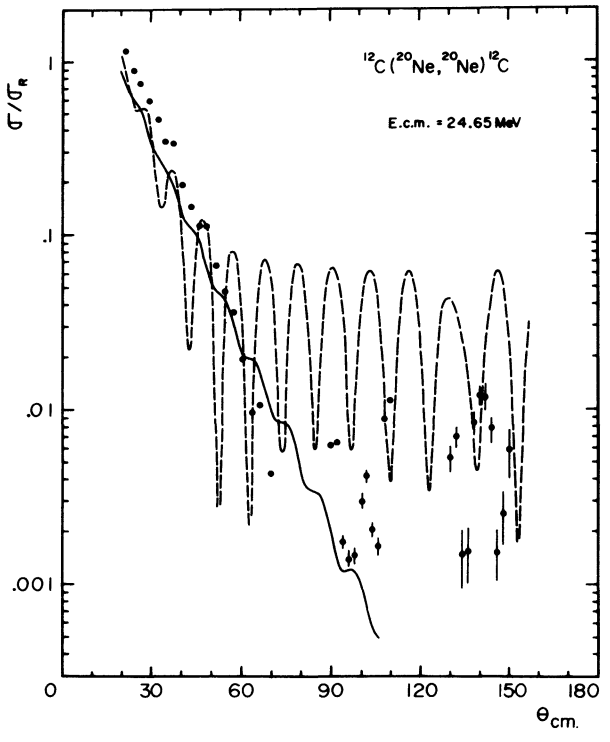

FIG. 2. — Angular distribution of the $^{12}C + {}^{20}Ne$ elastic scattering at 24.7 MeV (C.M.). Full line = optical model predictions with the potential of reference [7]. Dashed line = optical model predictions with the potential of reference [8].

As shown in the same figure, the experimental data lie between the predictions of the optical-model potential proposed in reference [7] for $^{12}C + ^{20}Ne$ and of Gobbi's potential [8] applied to the same system. The latter appears to be too transparent whereas the former allows for too much absorption. It is interesting to note that the disagreement between the data and predictions of the optical-model potential of reference [7] increases with angle. Such a conclusion is also supported by figure 2 where the angular distribution at 24.7 MeV (C.M.) incident energy is compared to the same optical-model predictions.

Up to 70° the strong decrease of the cross-section with angle may be interpreted as due to a strong absorption, as proposed in reference [7]. At more backward angles, the angular distribution is very rapidly oscillating, with a period close to 10° (C.M.). Even though it does not extend to the utmost backward angles, it shows no evidence for an elastic transfer contribution, which would involve a very improbable 8-particle transfer.

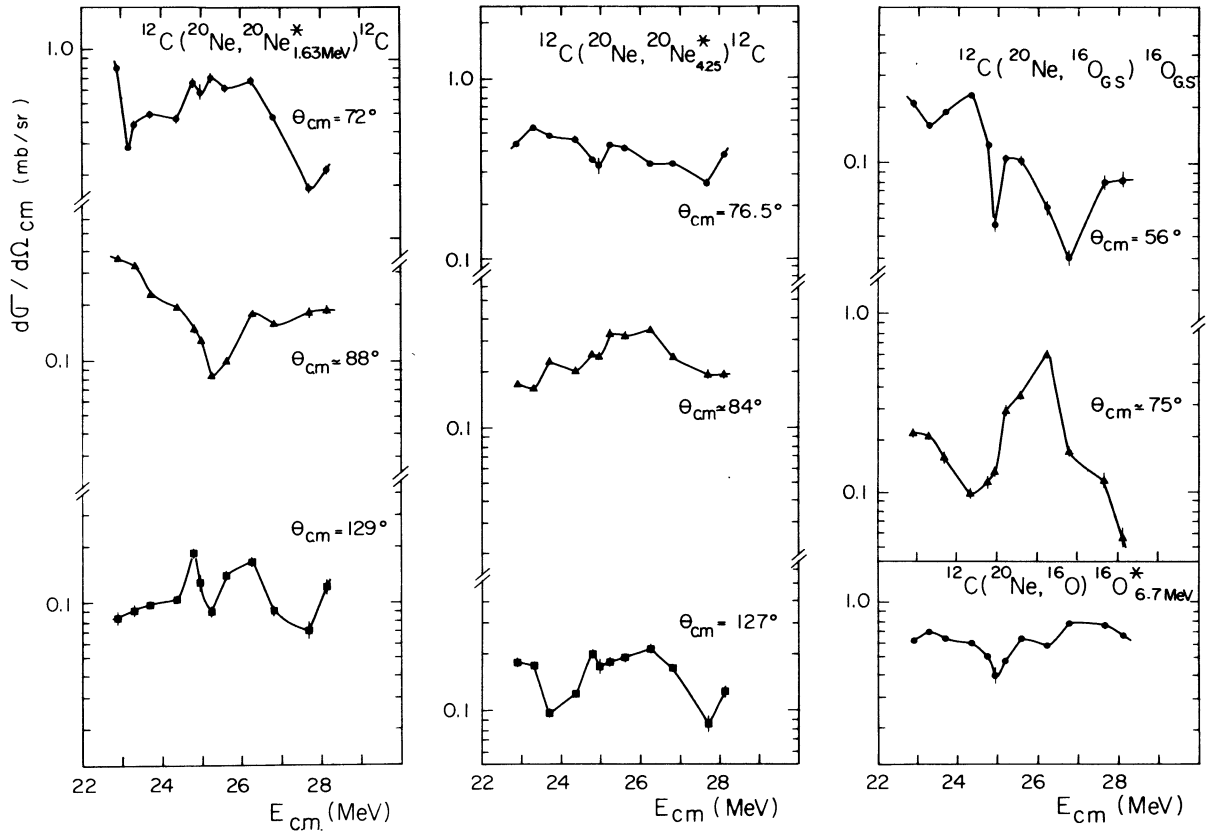

FIG. 3. — Excitation functions for the reaction channels $^{16}O_{6-7\,MeV}$ corresponds to the 4 excited states of ^{16}O at 6.05 MeV (0^+), 6.13 MeV (3^-), 6.92 MeV (2^+) and 7.12 MeV (1^-), at $\theta_{C.M.} \simeq 62°$.

In figure 3 are presented the excitation functions for several reaction channels, namely the inelastic scattering to the 2^+, (1.63 MeV) and the 4^+, (4.25 MeV) excited states of ^{20}Ne, and the 4-particle transfers to the ground state and to the 6-7 MeV excitation energy doublets in ^{16}O. These channels were chosen because of their ability to carry away the angular momentum brought in by the entrance channel. A strong structure only appears for the 4-particle transfer leading to the ground state of ^{16}O, for which the results agree with those of the inverse reaction studied in reference [5]. The lack of structure in the inelastic scattering excitation function should not be too surprising. This is strongly reminiscent of $^{16}O + ^{16}O$ inelastic scattering where, with a comparable angular momentum matching, there is no structure in the inelastic excitation function. 4-particle transfer to the 6-7 MeV doublets of ^{16}O presents a more intriguing behaviour. From 1-matching considerations, the 3^- component of these doublets is in a favorable position and according to the analysis performed by Rossner *et al.* [6], this should imply a large cross section, whereas the 0^+, 1^- and 2^+ levels should exhibit smaller cross sections. The data collected so far indicate, quite contrarily, that the contributions of both doublets are of the same order of magnitude. To elucidate this unexpected and interesting behaviour, a more complete experimental and theoretical analysis is necessary.

Finally, it could be worthwile to mention a small but persistent irregularity present on every excitation function at about 25 MeV. However, such an irregularity does not appear in the $^{20}Ne(^{12}C, \alpha)^{28}Si$ data published by the M.I.T. Brookhaven group [9].

The important point of this study is the strong structure observed in the elastic scattering excitation function, at 90° and 130° (C.M.). The $^{12}C + ^{20}Ne$ system appears to be intermediate between the $^{16}O + ^{16}O$ and $^{18}O + ^{18}O$ systems with regard to both the structure and the magnitude of the cross-sections. This can be related to the fact that, in this case, only few direct reaction channels are able to carry away the entrance angular momentum, whereas in the $^{18}O + ^{18}O$ case, a very large number of channels exist. In the $^{16}O + ^{16}O$ case, there are none, at least up to 30 MeV (C.M.) incident energy. As the energy rises, the still limited number of these reactions channels increases, resulting in a reduction of the observed elastic cross-section with however a persistent structure [10]. In the $^{12}C + ^{20}Ne$ case, the integrated cross-sections of these channels (2^+ and 4^+ inelastic scattering) were crudely evaluated and amount to about 100-150 mb. It can be noticed this represents half of the difference between the reaction cross-sections predicted by the (somewhat too absorptive) Vandenbosch's potential [7], and the transparent Gobbi's potential [8]. This can explain the intermediate behaviour of the $^{12}C + ^{20}Ne$ elastic scattering.

Finally, the study of the $^{12}C + ^{20}Ne$ system confirms nicely that angular momentum considerations [3] can provide a reliable tool for predicting the qualitative differences for absorption in heavy ion reactions.

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